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Introduction

The pervasive nature of weather and climate and the difficulties in adequately predicting their impact on beef cattle often lead to inadequate management strategies and tactics, resulting in a situation of coping as the need arises. This can lead to "management by crises" rather than rational decisions. The objective of this report is to summarize some of the known responses of cattle to their thermal environment and to address ways by which adverse impacts can be reduced. The discussion is based on results from MARC and other research stations.

General observations: Domestic cattle fall into two main classifications: European *Bos taurus* breeds (e.g., Herefords, Angus, Shorthorns, and the so-called exotic breeds) which evolved in temperate or cold regions and *Bos indicus*, or Zebu, breeds which evolved in tropical regions. *Bos taurus* breeds carry genes for higher production potential in moderate to cold climates when nutrition and other factors are non-limiting. In hot weather, the *Bos taurus* breeds are more susceptible to reduced performance than *Bos indicus* cattle, although the latter can also be adversely affected by heat effects on physiological and productive functions. The adaptability of cattle to relatively low temperatures is the result of several factors, including heat produced during roughage digestion, tissue, and a relatively lower surface area to mass ratio than for smaller species, which minimizes the rate of heat loss per unit of mass.

Body temperature represents the integrated response of an animal to various internal and external factors. Body temperature stability is generally considered an essential element for maximum productivity of cattle. However a diurnal cycling of up to 2°F body temperature can occur even in quite moderate thermal conditions. Constancy of body temperature, *per se*, may be less important to productivity than disruption of the normal cycling of body temperature caused by weather or other potential stressors. The impact of that disruption on physiological factors is presently unknown but may ultimately be expressed in terms of production, reproduction, efficiency and health. Obviously, the impact of cold or hot conditions on beef cattle performance needs to be assessed as a basis for rational management.

Performance responses to weather and climate

Conditions for optimal performance of farm animals have generally been established in terms of air temperature. Figure 1 shows temperature ranges for optimal performance and critical temperatures and also provides information on broader temperature zones wherein production and efficiency losses are nominal. The variance of acceptable conditions in terms of life stages is also illustrated. The impact of the thermal environment on nutritional requirements of cattle, reviewed by the National Research Council in 1981 ("Effect of Environment on Nutrient Requirements of Domestic Animals," National Academy Press, Washington, D.C.), indicated the effect to be significant in either extreme heat or extreme cold. Reproductive processes such as spermatogenesis, conception, and embryo survival are particularly vulnerable to high temperatures. Young calves are susceptible to cold weather because of relatively large surface area to mass ratios, small amounts of insulative tissue, and little or no heat produced by fermentation processes in the rumen.

The degree to which losses from depressed performance and death are related to the thermal environment is dependent to some extent on condition of the animals, dietary energy levels, health status, etc. An indication of such losses can be obtained from relationships developed from feedlot data in eastern Nebraska (Table 1). Feedlot No. 1 data were from 50,000 animals (60 pct Angus crossbreds, 30 pct Herefords, and 10 pct Charolais) fed during approximately 100-day periods in a commercial unit between August 1977 and April 1980. Feedlot No. 2 data were from 700 animals (Hereford, Angus, and Hereford-Angus crossbreds) kept in MARC feedlot pens for 250- to 270-day periods between 1972 and 1979. Those weather factors primarily associated with cold conditions were indicated to be most strongly related to deaths, although four of the five significant terms in the death loss equation (Feedlot No. 1) were related to heat stress (reflecting hot, humid, calm conditions). The weight gain relationship for Feedlot No. 1 indicated that cold, windy days with snow present in the winter or hot, humid summer conditions had the most effect on gain/day. Average wind speed and the diurnal temperature range were the factors of highest influence on gain/day of animals in Feedlot No. 2; however, the gain/day equation for Feedlot No. 1 predicted gain/day for Feedlot No. 2 with the same level of accuracy as the equation developed solely from Feedlot No. 2 data. Weather was more strongly related to cattle deaths than to weight gain variations; weather variables for Feedlot No. 1 in Table 1 accounted for 86 percent of the death variance and 36 percent of the gain variance.

These results to some extent reflect the finality of the death measure as opposed to the potential for recovery from weather effects on short term gains during the longer-term total feeding period. Results of this study further indicate that temperature alone is inadequate to represent the impacts of weather. Humidity, precipitation, and wind speed are strong modifiers of temperature effects; likewise, solar radiation is undoubtedly a further modifier of temperature, but data were unavailable for these analyses.

Financial losses from the pervasive weather-related gain reductions far exceeded those resulting from the relatively few deaths in the above study. To illustrate this point, the direct financial loss for each animal attributable to cold weather, based on the results of this study, is $14.14 (cattle in the feedlot for 100 days with 30 days having minimum temperatures below 0°F; value of animal at marketing = $.60/lb). The value of animals lost by death, again based on results of this study and the same assumptions, is less than 10 percent of the weather-related gain reductions.

A large-scale Colorado study to evaluate the effects of cold weather on digestion, growth, and efficiency of feedlot animals indicated that cold slightly reduced daily dry matter intake while increasing the net energy for maintenance requirement, resulting in reduced gains and feed efficiency. However, some partially offsetting positive effects were also found, including approximately 1 percent lower crude protein requirement and the ability of cattle to use relatively greater proportions of non-protein nitrogen at 32°F compared with 68°F.

The impact of winter weather conditions over a 15-year period, evaluated in terms of growth and feed conversion for beef cattle as predicted by the AGNET Beef Grower Model[2], was

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[2]Based on recent analyses as described in the preceding paragraphs, the current Beef Grower Model may not adequately reflect the influence of adverse weather conditions. However, use of the current model to compare variations among years, as described in this paragraph, should remain valid on a relative basis.

Table 1.—Relationships between mortality or gain and weather factors for feedlot cattle

Feedlot

No. 1: Death loss $= 8.33 + 0.003W_{35} - 0.286W_{30} - 0.089W_1 - 0.343W_{33} + 0.416W_{23}$

Gain/day $= 1.24 - 0.006W_{19} - 0.006W_{22} + 0.004W_{33}$

No. 2: Gain/day $= -0.484 + 0.114W_{28} + 0.049W_7$

Where the weather factors are defined as follows for the feeding period:

W_1 = percentage of days for which temperature exceeded 80°F
W_7 = percentage of days with a temperature range greater than 45°F
W_{19} = percentage of days with snow cover
W_{22} = percentage of days with THI* greater than 79
W_{23} = percentage of days with THI* greater than 84
W_{28} = average wind speed (mph)
W_{30} = percentage of days with average wind speed less than 4.5 mph
W_{33} = percentage of days with average windchill** over 1200 base value
W_{35} = sum of THI degree-days above 84 base value

THI = Temperature-Humidity Index $= 0.55t_{db} + t_{dp} + 17.5$
where t_{db} = drybulb temperature, °F
t_{dp} = dewpoint temperature, °F

**Windpchill $= (10.5 + 10\sqrt{V/3.28} - V/3.28)(50.78 - t_{db}/1.8)$ in kcal/m^2 – hr
where V = windspeed, ft/sec
t_{db} = drybulb temperature, °F
Values greater than 1200 indicate "bitterly cold" conditions.

Table 2.—Relative effects of winter weather on beef cattle growth and feed conversion for a 15-year period at Grand Island, Nebraska, based on the AGNET Beef Grower Model using actual weather records

For Winter Period Starting Oct 1	Standard Conditions[a] Growth	Standard Conditions[a] Feed Conv.	Hock-Deep Mud[b] Growth	Hock-Deep Mud[b] Feed Conv.	Mud + HE Diet[c] Growth	Mud + HE Diet[c] Feed Conv.	Description of Winter Season: Temperature	Description of Winter Season: Snow
1964	99.1	101.2	99.4	100.5	100.6	99.3		
1965	101.1	99.3	100.8	98.9	101.2	98.8		
1966	100.6	99.3	100.8	99.1	101.2	99.1	Above normal	Below normal
1967	100.6	99.2	100.4	99.4	99.9	99.7	Near normal	Much below normal
1968	99.1	100.8	98.5	101.0	99.3	101.1	Below normal	Much above normal
1969	99.6	100.2	98.5	101.1	99.9	100.1	Near normal	Near normal
1970	100.1	100.1	99.4	100.4	99.3	100.4	Near normal	Slightly above normal
1971	101.1	99.3	99.9	99.7	99.9	100.0	Near normal	Much below normal
1972	100.1	99.9	99.4	100.2	99.3	100.4	Near normal (Dec. cold)	Much above normal
1973	100.6	99.2	100.4	99.0	100.6	98.8	Near normal	Much above normal
1974	99.6	100.6	99.0	100.8	99.9	100.0	Near normal (Feb. cold)	Slightly above normal
1975	101.1	98.7	100.8	98.6	100.6	99.3	Above normal	Slightly above normal
1976	100.1	99.7	99.4	99.8	99.3	100.7	Near normal (cold early, mild later)	Slightly below normal
1977	99.1	101.0	99.9	100.0	100.6	99.3	Near normal (mild early, cold later)	Above normal
1978	98.2	101.8	98.5	101.0	98.1	102.0	Much below normal	Much above normal

[a]"Standard Conditions" refer to medium-frame Hereford-Angus crossbred steers of average condition, fed a medium energy diet (NEG/NEM = 37/67) on a hard-surfaced lot.
[b]"Standard Condition" except a dirt lot which became hock-deep mud at temperatures between 25 and 45°F.
[c]"Standard Condition" except for a dirt lot with cattle fed a high energy diet (NEG/NEM = 47/77).

assessed on the basis of Grand Island, Nebraska, climatological records. The results, based on medium frame Hereford-Angus steers fed a medium energy diet over a 350-lb growth period, are given in Table 2. All values are relative to the average growth rates and feed conversions for the 15-year period. On the basis of "standard conditions," the winters can be classified in terms of impact on performance:

Above-average growth, better-than-average feed conversion:

- Quite mild - 1965, 1971, 1975
- Mild - 1966, 1967, 1973

Near normal growth and feed conversion:

- 1969, 1970, 1972, 1976

Below-average growth, worse-than-average feed conversion:

- Moderately severe - 1964, 1968, 1974, 1977
- Severe - 1978.

The average gain for animals maintained under "standard conditions" in hard-surfaced lots (no mud) for all years was 1.69 lb/day, with a feed conversion of 9.56 lb feed/lb gain. The best years (1965, 1971, and 1975) for growth indicated a predicted gain of 1.71 lb/day, with the least feed required in 1975 (9.44 lb feed/lb gain). The 1978-79 winter had the most extreme impact of the 15 years examined for Grand Island with growth and feed conversion of 1.66 lb/day and 9.73 lb feed/lb gain, respectively. While the differences in relative performance between the worst and best years do not seem large, they do represent a difference of six extra days to grow 350 lb and a 3 percent higher feed bill. The existence of hock-deep mud (assumed when temperatures were between 25 and 45°F) in a dirt lot for otherwise similar animals and feed indicated the average gain for all years to be reduced to 1.62 lb/day with a feed conversion of 9.98 lb feed/lb gain. The differences between worst and best years were five extra days to gain 350 lb and a 2 1/2 percent higher feed bill. Feeding a higher energy ration to animals in a dirt lot (same hock-deep mud assumption) increased the average gain for all years to 2.37 lb/day with a feed conversion of 7.06 lb feed/lb gain. The differences between worst and best years were seven extra days to gain 350 lb and a 5 percent higher feed bill. Similar analyses with large exotic crossbred animals indicated adverse weather to have nearly twice the impact on the differences between worst and best years in the various situations evaluated for the Hereford-Angus crossbreds. For example, hock-deep mud added ten days to the feeding period for the exotic crossbreds to gain 350 lb, and required 4 3/4 percent more feed compared with the five extra days and 2 1/2 percent more feed for the Hereford-Angus crossbreds. However, the exotic crossbreds needed about 20-22 fewer total days for gaining 350 lb than did the Hereford-Angus crossbreds under comparable "standard" conditions.

Altered performance in terms of health and well-being of farm animals can also result from adverse environments. For example, gestation length and birth weights, which indirectly affect neonatal health, are significantly reduced in hot weather. Further, animal stress resulting from hot weather can result in activation of latent viruses to make a favorable environment for secondary bacterial infection, or it can result in increased intensity of a disease by impairing the immunologic function.

Performance losses of farm animals are highly dependent on the degree of acclimation (short-term adaptation). There is also a widely recognized ability of *ad lib*-fed growing animals to "catch up" (compensate) subsequent to moderate levels of nutritional stress; similar compensatory growth after thermal stress is an evident parallel. Within the limits of compensatory capabilities of growing farm animals, there is a reduced need for environmental modification. There is also some evidence of compensatory performance in lactating cows, although the likelihood of complete compensation appears small.

Behavioral patterns of farm animals are definitely altered by adverse environments as they attempt to maintain body temperature. During cold weather, they adjust posture, huddle with other animals, and usually increase feed intake. In hot weather, feeding times are altered, feed intake is reduced, water intake is increased, and heat relief measures (e.g., shade, wind) are sought. This flexibility in behavior can serve to limit performance losses and is a major contributor to the nominal losses over the broad range of temperatures noted in Figure 1. However, cattle do not always behaviorally respond in their best interest, as when they bunch in the presence of biting flies

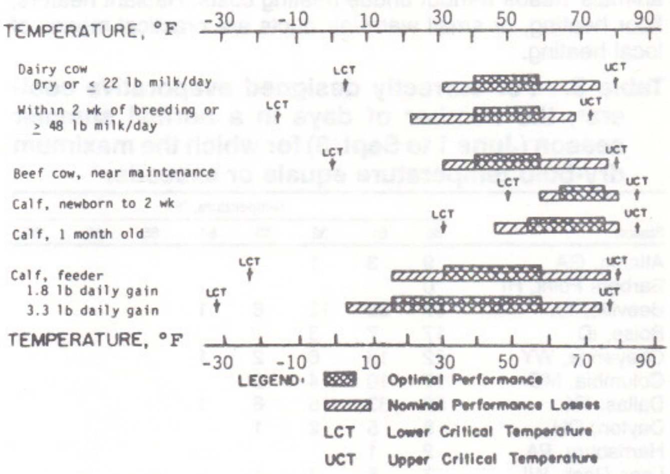

Figure 1—Critical ambient temperatures and temperature zones for optimal performance and nominal performance losses in *Bos taurus* cattle. Values shown represent the large majority of the designated population; variations in health and general physical conditions, acclimation to seasonal conditions, adequacy of feed and water, freedom from parasites and other pests, and thermal factors other than temperature can alter the response of individual animals. Wetted skin and hair, or air velocities above 1 ft/sec, shift all temperatures upward; elevated humidity or exposure to solar radiation shift all temperatures downward.

during hot weather, which may increase heat stress. Behavior also is a significant factor in limiting performance losses only to the extent that management practices permit its expression. If, for example, the animal has no access to shade in hot weather, it will not be able to reduce thermal stress resulting from solar radiation. Conversely, animals without shelter in winter will not be able to voluntarily escape thermal stress that may be imposed by wind, precipitation, or mud.

Coping with climate and weather

For weather conditions within the limits noted for optimal performance or nominal losses, there is little need for special shelter or environmental modification practices for cattle, other than newborn and very young calves. Conversely, stress-limiting protective measures can be helpful in extreme conditions to assure well-being and survival of the animals for further productive performance. Newborn calves benefit from shelter from chilling winds and precipitation during cold weather. Animals nearing market weight are particularly vulnerable to hot weather, especially during periods of high humidity. Special measures may be required during handling and transport of market animals during extreme cold or heat. A Livestock Weather Safety Index, developed by the Livestock Conservation Institute on the basis of death losses during shipping of market animals, serves as a basis for livestock advisories in hot weather. The categories, associated with the Temperature-Humidity Index as defined in Table 1 are:

THI value	*Category*
70 or less	Normal
71-78	Alert
79-83	Danger
83 or above	Emergency

Advisory forecasts of "danger" or "emergency" category conditions issued by the U.S. National Weather Service provide a basis for tactical actions, such as postponing stressful activities for animals or taking measures to limit stress (e.g., handling in early morning, wetting the animals, etc.).

The impact of sub-optimal conditions which are not life-threatening is less clear. Although we do not yet have adequate information to indicate cost-benefit ratios from the application and operation of various environmental modification practices, the rest of this section focuses on possible alternatives for consideration by cattle managers.

To effectively alter the microclimate of an animal through housing or environmental modification, we must consider altering one or more of these factors: temperature of the surrounding surfaces (e.g., by providing shades or other infrared radiation shields); air temperature (e.g., by providing auxiliary heating or cooling); air velocity (e.g., by windbreaks or augmenting natural airflow with fans); air vapor pressure (e.g., by evaporating water); radiation shape factors; conductivity of surfaces that an animal might contact; and protection from or augmenting precipitation (e.g., by shelters or sprinklers).

Open or Partially Enclosed Shelters: Providing animals with adequate opportunity for behavioral thermoregulation (access to shades, walled enclosures, and other relatively passive alternatives) should receive first consideration, as such responses are complementary to physiological regulation and require minimal energy use. Cattle have minimal shelter requirements at most life stages, as noted in Figure 1; an exception is the newborn calf, particularly in cold, wet weather.

a. *Hot conditions*: Shades and other minimal measures should be thought of as a form of insurance for protecting farm animals in hot climates. The most effective shades are trees, as they provide protection from sunlight combined with the radiation sink effect created by the relatively cool leaves as a result of evaporating moisture. However, trees are not always available for livestock shades. Hay or straw shades are the most effective artificial shade materials; solid shade provided by sheet metal painted white on top is the next most effective. Slats or other shade materials with less than total shading capabilities are considerably less effective; for example, slatted snow-fencing with approximately 50 percent openings is only 59 percent as effective as new aluminum sheeting for shading animals.

Shades should be 12 to 14 ft high in areas with clear, sunny afternoons to permit maximum exposure to the relatively cool north sky, which acts as a radiation sink. However, in areas with cloudy afternoons, shades of 7 to 9 ft in height are more effective, as they limit the diffuse sky radiation received by animals beneath the shades. The amount of shade area needed for young cattle is 7-1/2 to 13 ft^2/head while larger cattle need at least 20 to 40 ft^2/head.

Partially enclosed shelters can further reduce the thermal radiation received by animals. Under clear-sky conditions, the average radiant heat load over a 7-h period was reduced almost 10 percent by the addition of a west wall to a simple shade. Adding more walls helped, but to a lesser degree.

Negative aspects of partially enclosed structures must be considered, such as decreased natural air velocity and sanitation. The use of wire or cable in shelters or open penning minimizes restrictions to air flow and permits maximum convective cooling. There are no guidelines for evaluating the benefits of open *vs* partially enclosed shelters, as the relative merits are dependent on many factors.

For installations subject to both hot and cold weather, open-front structures facing to the south with large doors or panels in the north wall are an acceptable compromise. Use of fans in hot weather should be considered if natural air velocity is less than about 7 ft/sec; however, increasing air velocity above 8 ft/sec adds little additional benefit.

b. *Cold conditions*: Exposure to cold, especially when combined with wind and precipitation as noted in the caption for Figure 1, can result in thermal demands which exceed an unprotected animal's homeostatic and metabolic capacity. Windbreaks and partially enclosed shelters for vulnerable animals in cold climates should, as with shades in hot conditions, be considered as a form of insurance. Depending on the specifics of design, windbreaks can provide effective downwind protection as far as 10-15 times their height. Windbreaks designed with 20-25 percent opening are more effective than solid barriers; an evergreen tree stand can be particularly effective, if available. Partially enclosed structures open to the south are preferred to permit warming of sheltered animals by solar radiation from the low winter sun angles.

Enclosed Shelters: Open or partially enclosed shelters are only effective to the extent that animals elect to use them; thermal comfort is not always an animal's highest priority in elective situations. Livestock managers often prefer to exert some control over the thermal environment of their animals by using enclosed structures. The degree of control ranges from naturally ventilated buildings operated as cold housing in winter and open shelters in summer, to insulated buildings operated to maintain a minimum of temperature variation year-round by means of tightly controlled ventilation and supplemental heating and/or cooling.

To the extent that enclosed shelters are capable of providing enhanced animal performance and well-being and are operated to realize that capability, they are an alternative for consideration in the decision-making process. However, it should be noted that both initial and operating costs go up much more rapidly than the derived benefits as the temperature is more closely controlled.

Other Alternatives

a. *Hot conditions*: In addition to adequate cool water for drinking, water can be an effective cooling agent. Cooling is obtained directly through wetting of the animal's surface and subsequent evaporation, or through indirect evaporative cooling of air which is used, in turn, to cool the animal. Cooling of hot surrounding surfaces can also reduce the radiation heat load on animals. Although the effectiveness of evaporating water is lessened by periods of high humidity, peak daily temperatures usually occur during mid-afternoon in the summer, when relative humidity is lowest.

Using water for direct wetting of the animals is an effective emergency measure. As a routine protective practice, wetting can be efficiently accomplished by sprinkler nozzles with a capacity of 2.5 to 5 gal/h and controlled by a timer to provide 5-10 min of spray out of each 20-30 min. Fogger nozzles, often mistakenly recommended for wetting animals, form fine droplets which cling to the animal's outer hair coat; sprinkler nozzles which wet the skin are more effective. Performance benefits from the use of direct wetting as a means of improved heat dissipation are still not confirmed, as some studies with cattle have shown measurable benefits but others have not. Increased air flow over wetted animals enhances the effectiveness of direct wetting, especially at low natural air velocities.

Evaporative coolers specifically designed to reduce air temperatures in livestock shelters can be quite effective. Use of evaporative cooling has expanded rapidly in hot climates because of its relatively simple design and favorable benefit:cost ratio. A correctly designed evaporative cooler will reduce the dry-bulb temperature of outside air entering the cooler by 80 percent of the wet-bulb depression. Table 3 provides an analysis of temperatures obtainable by evaporative cooling at various locations, which indicates that air temperatures of 85°F or less can normally be attained in all regions of the U.S.

b. *Cold conditions*: Use of supplemental heating is usually restricted to newborn or very young calves, particularly during cold, wet weather. Straw bedding can reduce heating requirements, and it should always be kept in mind that the immediate surroundings of the animal are primarily what influence heat loss. Providing heating for a localized area will often meet the animals' needs without undue heating costs. Radiant heaters, floor heating, or small warm-air ducts are practical means of local heating.

Table 3.—For correctly designed evaporative coolers[a], the number of days in a normal summer season (June 1 to Sept. 3) for which the maximum dry-bulb temperature equals or exceeds:

	Temperature, °F							
Station	80	81	82	83	84	85	86	87
Atlanta, GA	9	3	1					
Barbers Point, HI	0							
Beeville, TX	57	32	12	6	1			
Boise, ID	17	7	3					
Cheyenne, WY	22	13	6	2	1			
Columbia, MO	17	10	4	2				
Dallas, TX	52	33	15	6	1			
Dayton, OH	8	5	2	1				
Harrisburg, PA	2	1						
Lone Rock, WI	7	5	3	1				
Massena, NY	2	1	1					
Memphis, TN	38	30	15	8	4	2	1	
Oklahoma City, OK	16	7	3	1				
Phoenix, AZ	29	14	5	2	1			
Sacramento, CA	3	1	1					
Sioux Falls, SD	6	3	1					

[a]Eighty percent of wet-bulb depression assumed. Temperatures within enclosed evaporatively cooled livestock structures would normally be within 2-3°F of air leaving the fully wetted cooler pad.

Summary

Short-term weather disturbances can alter the physiological state of cattle. In terms of performance, however, cattle are relatively insensitive to moderate and cool weather and climates. Heat or extreme cold can cause adverse effects, especially when combined with compounding factors (e.g., precipitation and wind or poor nutrition in cold or high humidity in heat). Newborn calves, market-weight cattle, and breeding animals are most vulnerable to adverse weather conditions. This report summarizes some recent research observations and ways of coping with adverse conditions which can improve the management of cattle. Alternatives available to individual livestock managers should be considered and selections made on the most rational basis possible (e.g., cost:benefit ratio, animal health); not all are profitable or acceptable in all situations. Environments established for maximum performance or efficiency of feed energy utilization are not necessarily optimal. The point cannot be emphasized too strongly that rational agricultural management must be based on valid information about the biological and production systems. Evaluation of the consequences which result from various alternatives logically involves economics and risks, but should also consider animal well-being, availability of resources, proven technological feasibility, and managerial capabilities.